AD-A091 345 NORTHWESTERN UNIV EVANSTON IL DEPT OF MATERIALS SCIENCE F/G 11/6
THRESHOLDS FOR FATIGUE INITIATION AND PROPAGATION AND PLASTIC W--ETC(U)
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REPORT DOCUMENTATION PAGE — READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A091345

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
THRESHOLDS FOR FATIGUE INITIATION AND PROPAGATION AND PLASTIC WORK IN HY80 AND HY130 STEELS

5. TYPE OF REPORT & PERIOD COVERED
Annual Report
9/1/79-8/31/80

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Morris E. Fine

16 Oct 80

8. CONTRACT OR GRANT NUMBER(s)
N00014-78-C-0565 NEW

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Northwestern University
Dept. of Materials Science & Engineering
Evanston, IL 60201

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
122208

11. CONTROLLING OFFICE NAME AND ADDRESS CODE N62880
Office of Naval Research Branch Office
Room 286, 536 S. Clark Street
Chicago, IL 60605

12. REPORT DATE
October 16, 1980

13. NUMBER OF PAGES
12

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

LEVEL II

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution is unlimited

Annual rept. 1 Sep 79-31 Aug 80

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DTIC SELECTED NOV 3 1980

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HY80, HY130, fatigue threshold, fatigue crack propagation rate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The effect of tempering temperature on the fatigue crack propagation rate (FCPR) in the mid-stress intensity range of HY130 austenitized at 815°C was determined. Three treatments giving the same hardness, R.C. 34, were selected: A - 10 hrs at 400°C, B - 5 hrs at 550°C, and C - $\frac{1}{4}$ hr at 650°C. There was little difference in the rates either when the testing was done in air (55% relative humidity) or dry argon. Previously, a ten times larger FCPR was observed in specimens tempered 1 hr at 610°C when the tests were carried out in air rather

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S/N 0102-LF-014-6601

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than dry argon. Changing the tempering furnace from a salt pot to a dry argon tube furnace and water quenching from 610° C rather than air cooling seemed to cure the problem. The threshold for macrofatigue crack propagation was measured in commercially pure iron in both center notch and side notch specimens. Both specimen geometries gave the same results, $\Delta K_{th} = 6\ MN/m^{3/2}$.

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DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING
THE TECHNOLOGICAL INSTITUTE
NORTHWESTERN UNIVERSITY
EVANSTON, IL 60201

Annual Report on

Thresholds for Fatigue Initiation and Propagation and Plastic Work in HY80 and HY130 Steels

ONR Contract #N00014-78-C-0565

For the Period

1 September 1979 to 31 August 1980

Principal Investigator:

Morris E. Fine, Professor of Materials Science & Engineering
Telephone: (312) 492-5579

October 1, 1980

INTRODUCTION

The objective of this research is to make a comprehensive study of the effect of heat treatment and microstructure on the initiation of fatigue cracks and on the fatigue crack propagation rate from the threshold stress intensity (ΔK_{th}) to the mid-range of stress intensity in HY80 and HY130.

The first phase which was completed August 31, 1979 by Dr. S. I. Kwun studied HY80 and HY130 samples which had been given the normal heat treatments. The results were summarized in the Progress Report of 1 September 1978 to 31 August 1979 for this grant[1] and a paper[2] has been submitted for publication.

Research in this laboratory has shown that the fatigue crack propagation rate in the mid-range of ΔK can be reduced to the approximate form

$$\frac{da}{dN} = A\frac{(\Delta K)^4}{\mu\sigma^2 U} \qquad (1)$$

where a is the crack length, N is the cycle number, ΔK is the stress intensity amplitude, μ is the shear modulus, σ is the 0.2% offset cyclic flow stress, U is the plastic work required for a unit area of fatigue crack propagation and A is a dimensionless constant whose value will be discussed later. The major contribution from this group was to devise a technique using foil strain gages for measuring U. Such measurements for HY80 and HY130 are reported in last year's report. When m in the Paris relation, $da/dN = C(\Delta K)^m$, is 4, U is independent of ΔK but when m is less than 4 U is a function of ΔK according to the equation

$$U = B(\Delta K)^n \qquad (2)$$

with $n = 4-m$.

The results to date for testing eq.(1) including the study of HY80 and HY130 are included in a review paper[3] and show eq.(1) to hold rather well with A as universal constant equal to $(2.9 \pm 0.9) \times 10^{-3}$ when meters, Joules, and meganewtons are used as units. The value of U for HY130 (for crack propagation in argon) was very small and it was, therefore, decided to first investigate the affect of tempering temperature on U and da/dN vs. ΔK.

Previously, Kwun and Fournelle[4] at Marquette University studied a 0.034Nb-0.08C steel and found that tempering at 400°C (5 hrs) rather than 550°C (10 hrs) resulted in a four times greater value of U even though the yield strengths were about the same. These authors proposed that the difference arises from a difference in composition and morphology of the carbide phase although this was not investigated.

Since HY130 contains V (0.064 wt.%) and C (0.10 wt.%), it was thought that similar results to the Nb steel might be obtained. Since eq.(1) has been shown to hold at least as a good first approximation, it was decided to measure da/dN vs. ΔK in the mid-ΔK region and use eq.(1) to give an indication of how U changed with heat treatment. This research is part of the Ph.D. thesis of Mr. Jain-Long Horng who began September 15, 1979. He will do the complete study stated in the objective of this research for his Ph.D. thesis.

RESULTS AND DISCUSSION

As last year, HY130 of the following composition, in weight percent, obtained from the U. S. Steel Research Laboratory, was used in the research.

	C	Ni	Cr	Mo	Mn	V	Si
HY130	0.10	5.33	0.49	0.57	0.35	0.064	0.23

The standard heat treatment for HY130 is austenitizing at 815° C followed by tempering 1 hr at 610° C.

After quenching from 815° C, there was no evidence for undissolved VC when specimens were examined at 1000 magnification in the optical microscope; therefore, an austenitizing temperature of 815° C was selected for a study of the effect of tempering temperature on the fatigue crack propagation rate. Samples were first austenitized at 815° C in argon, water quenched and then tempered for various times at 400, 500, and 650° C. Rockwell C hardness versus tempering time is shown in Fig. 1. The hardness falls off more rapidly with time, of course, as the tempering temperature is increased; however, there is some evidence for secondary hardening on tempering at 550° C presumably due to VC replacing Fe_3C. Three tempering treatments giving approximately the same Rockwell C hardness (34) were chosen.

A	10 hrs	at	400° C
B	5 hrs	at	550° C
C	$\frac{1}{4}$ hr	at	650° C

As previously da/dN was measured versus ΔK in panel specimens 100 mm by 3.5 mm by 25 mm containing a 3 mm by 0.2 mm center notch introduced by spark machining. All heat treatments were done after specimen preparation but before spark machining. The crack lengths were measured with a 40X telemicroscope. The results for 55% relative humidity air and dried argon are shown in Figs. 2, 3, and 4. The results for argon were all somewhat lower than those in air, particularly for the 400° C tempered specimens at low ΔK. There was, however, no dramatic difference in the da/dN curves for the three heat treatments as with the Nb steel. Table I compares the results at $\Delta K = 20$ $MN/m^{\frac{3}{2}}$.

TABLE I.

	da/dN at 20 $MN/m^{\frac{3}{2}}$ in m/cycle	
	Air	Dry Argon
A 10 hrs, 400°C	6×10^{-8}*	4×10^{-8}
B 5 hrs, 550°C	5×10^{-8}*	4×10^{-8}
C $\frac{1}{4}$ hr, 650°C	5×10^{-8}*	5×10^{-8}
D 1 hr, 610°C (Horng)	7×10^{-8}*	5×10^{-8}
D 1 hr, 610°C (Kwun)	8×10^{-7}**	5×10^{-8}

* 55% relative humidity
** 47% relative humidity

The absence of a large effect of heat treatment on da/dN in the mid-ΔK region in HY130, as observed in the 0.034 wt.% Nb-0.08 wt.% C steel[4] was disappointing. We plan to try higher austenitizing temperatures as well as dual phase microstructures. The latter should be particularly effective in raising ΔK_{th}.[5]

Previously, Dr. Kwun[1] reported that there was a large difference in the da/dN versus ΔK curves of HY130 tempered 1 hr at 610°C when tested in 47% relative humidity air and in dry argon. The absence of such an effect for the 650°C was surprising. Therefore, the standard HY130 treatment, tempering 1 hr at 610°C (Treatment D), was studied again. The results are shown in Fig. 5 and no large environmental effect is noted. The previous and present results are compared using "smoothed straight" lines in Fig. 6 and in Table I at $\Delta K = 20$ $MN/m^{\frac{3}{2}}$. While there is very good agreement in dry argon between the Kwun and Horng results, there is not in air. Dr. Kwun's da/dN vs. ΔK line for air represents data for several samples. There is a real but as yet unexplained difference between the two sets of data. It should be noted that Kwun tempered in a salt bath and air cooled his specimens; Horng conducted the tempering in dry argon and drop quenched his samples into water. Seggregation to grain boundaries may have occurred

during the slow cooling and this may be responsible for the environmental enhancement of fatigue crack propagation rate observed. Further research is obviously needed to understand the observed effect. It is very important to learn the conditions for fast fatigue crack propagation in HY130 in air. As shown in Table I, it does appear that tempering 1 hr at 610°C gives the fastest fatigue crack propagation rate in air of all the tempering times and temperatures tried even if the Kwun results are disregarded.

EFFECT OF SPECIMEN GEOMETRY ON MEASUREMENT OF ΔK_{th}

In the previous annual report[1] threshold values for macrofatigue crack propagation were reported for HY80 and HY130 given the standard heat treatment* as well as for 4140 tempered at 650°C. These results are also in the paper[3] which has been submitted for publication. The values which were 4.2 $MN/m^{\frac{3}{2}}$ for HY80 and 3.8 $MN/m^{\frac{3}{2}}$ for HY130 ($R = 0.05$) seemed low compared to some other published values for steels.[6] It was, therefore, decided to make measurements on commercially pure iron (0.017 wt.% C) to compare with literature results. Measurements were made on both center notch and side notch specimens by Dr. S. I. Kwun who returned to Northwestern from the Korean University for a portion of the summer. To reduce the size of the plastic zone, the specimens were, after furnace cooling from 850°C, work hardened by stretching 15% prior to introducing the notch. Values for ΔK_{th} of 6.08 and 6.05 $MN/m^{\frac{3}{2}}$ were obtained for the center and side notch specimens, respectively. This is extremely good agreement. This may be compared to a value of approximately 7 $MN/m^{\frac{3}{2}}$ reported by Masounove and Bailon[7] for low C steel of ordinary grain size. This experiment further validates our results for ΔK_{th} of HY80 and HY130.

* The standard heat treatments are for HY80 austenitizing at 900°C followed by tempering 1 hr at 700°C and for HY130 austenitizing at 815°C followed by tempering 1 hr at 610°C.

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2. S. I. Kwun and M. E. Fine, "Fatigue Macrocrack Growth in Tempered HY80, HY130, and 4140 Steels: Threshold and Mid-ΔK Range", submitted to Fatigue of Engineering Materials and Structures, Oxford.

3. P. K. Liaw, S. I. Kwun and M. E. Fine, "Plastic Work of Fatigue Crack Propagation in Steels and Aluminum Alloys", Metallurgical Transactions, in press.

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PERSONNEL

Dr. S. I. Kwun, Postdoctoral Research Associate 9/1/78 to 8/8/79, half-time August 1980. Mr. Jain-Long Horng, Graduate Research Assistant 9/79 to present.

PUBLICATIONS

1. S. I. Kwun and M. E. Fine, "Fatigue Macrocrack Growth in Tempered HY80, HY130, and 4140 Steels: Threshold and Mid-ΔK Range". Submitted to Fatigue of Engineering Materials and Structures.

2. P. K. Liaw, S. I. Kwun and M. E. Fine, "Plastic Work of Fatigue Crack Propagation in Steels and Aluminum Alloys". In press, Metallurgical Transactions. Also supported by AFOSR.

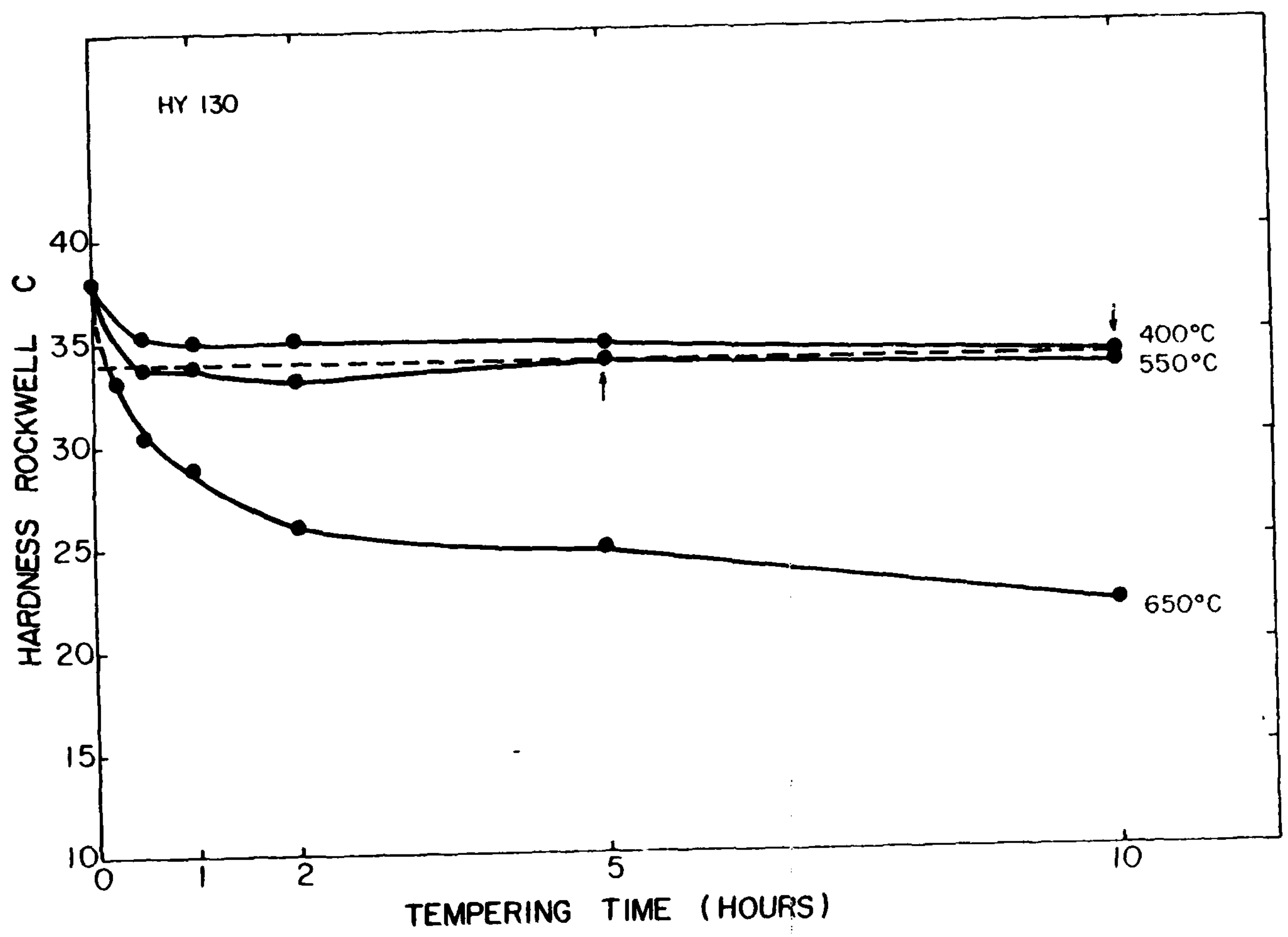

Fig. 1. Rockwell C hardness of HY130 austenitized at 815° C and tempered at the temperatures indicated.

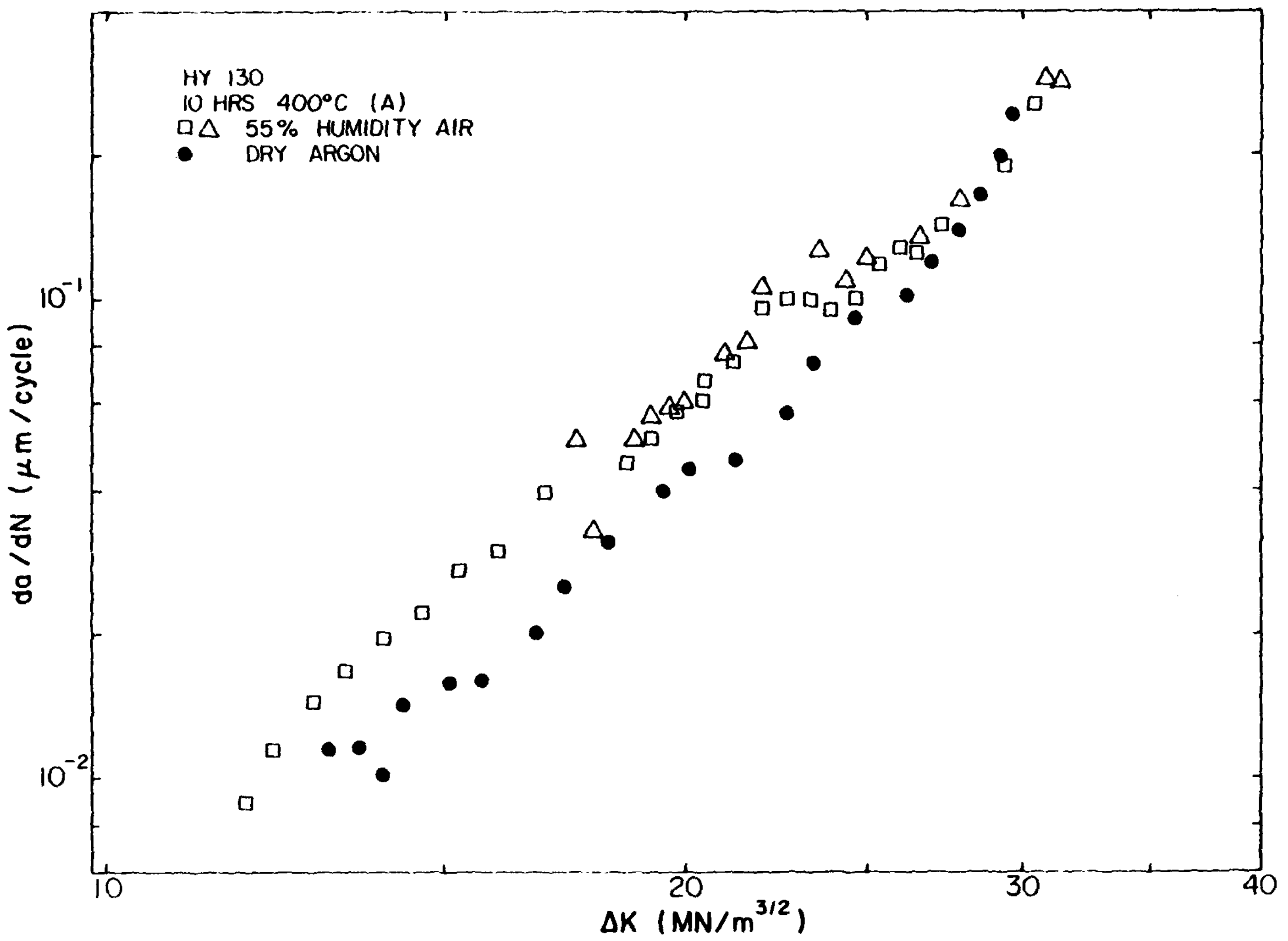

Fig. 2. Fatigue crack propagation rate versus ΔK of HY130 austenitized at 815°C and tempered 10 hrs at 400°C.

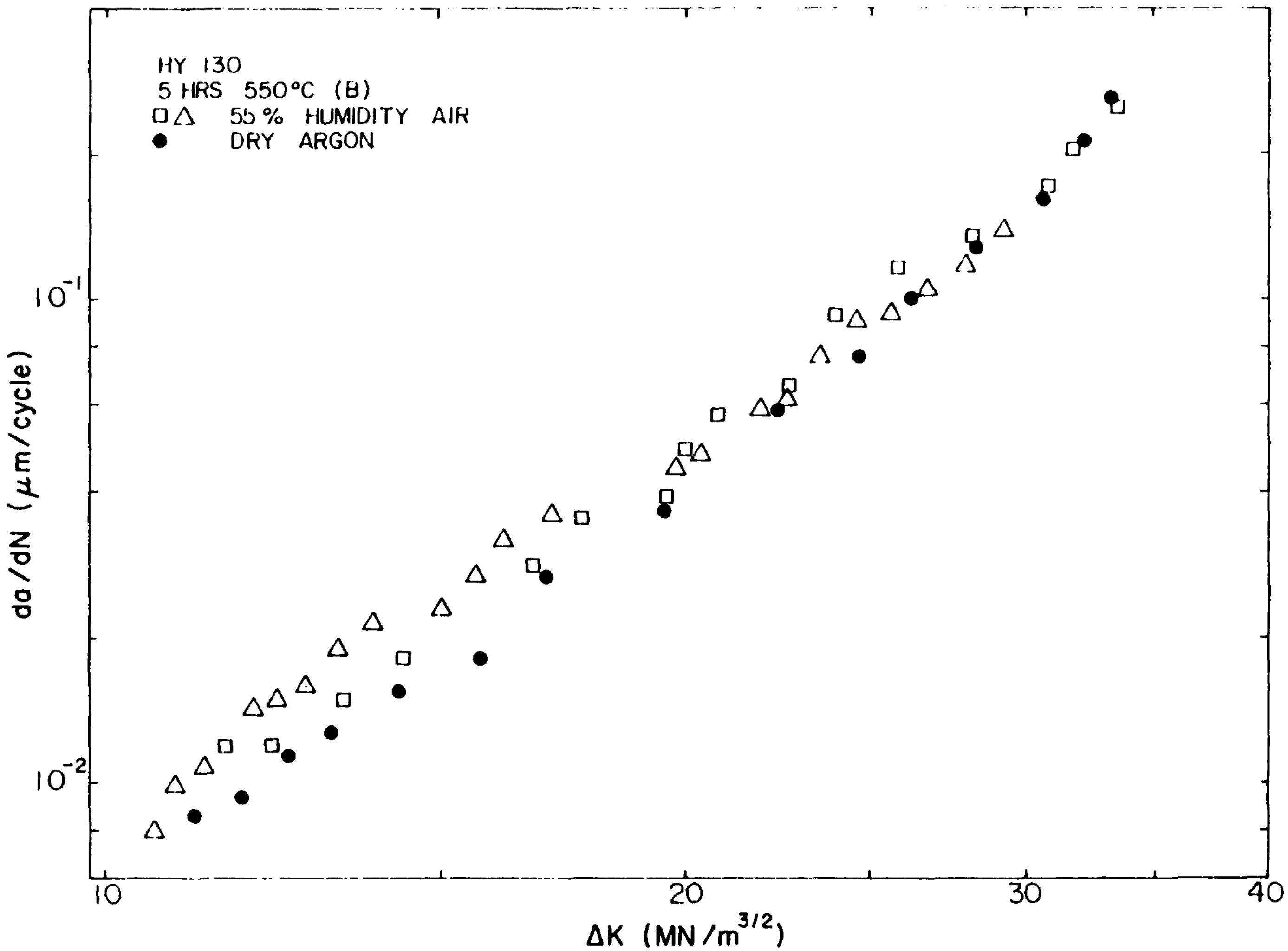

Fig. 3. Fatigue crack propagation rate versus ΔK of HY130 austenitized at 815°C and tempered 5 hrs at 550°C.

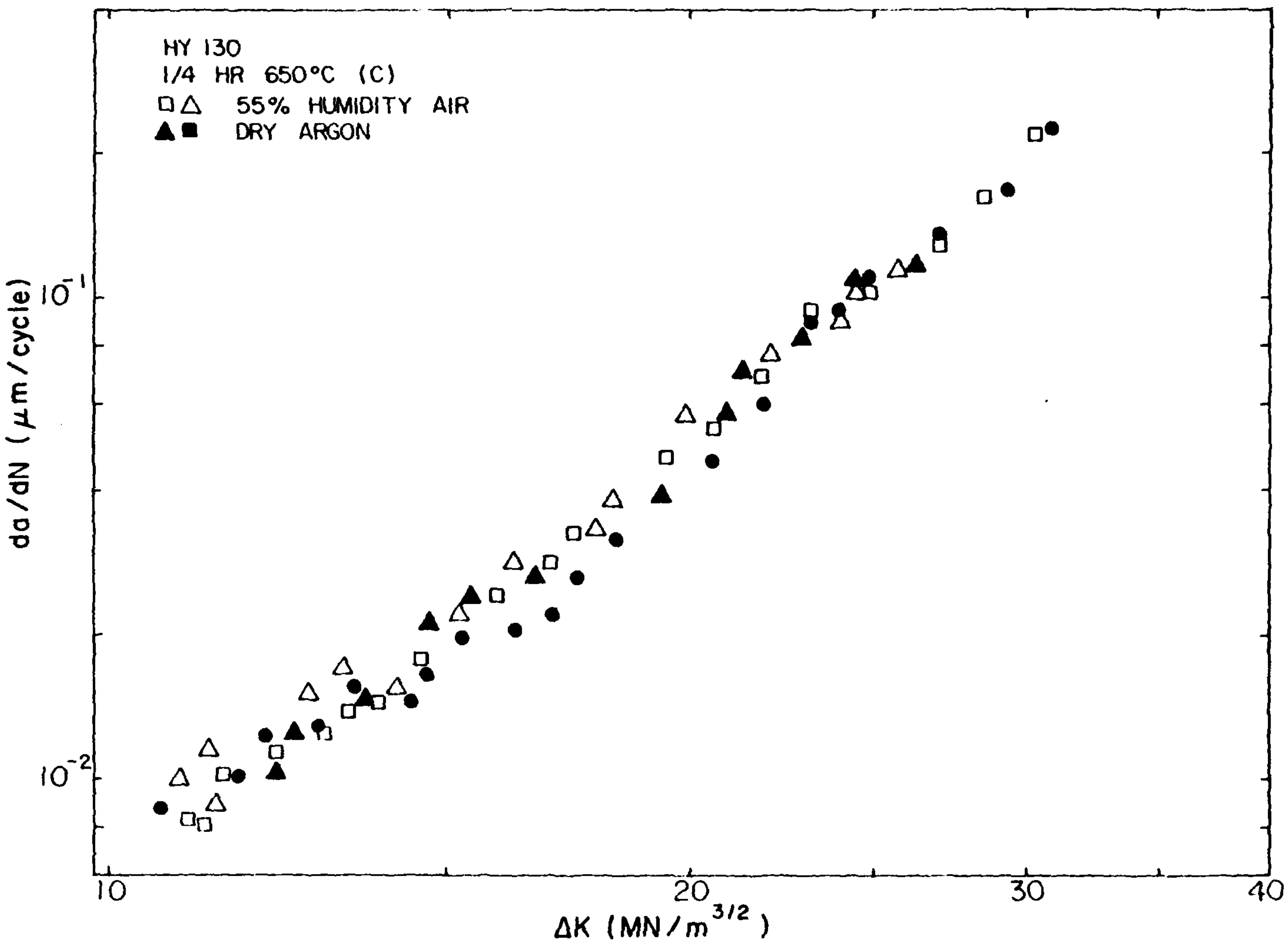

Fig. 4. Fatigue crack propagation rate versus ΔK of HY130 austenitized at 815°C and tempered $\frac{1}{4}$ hr at 650°C.

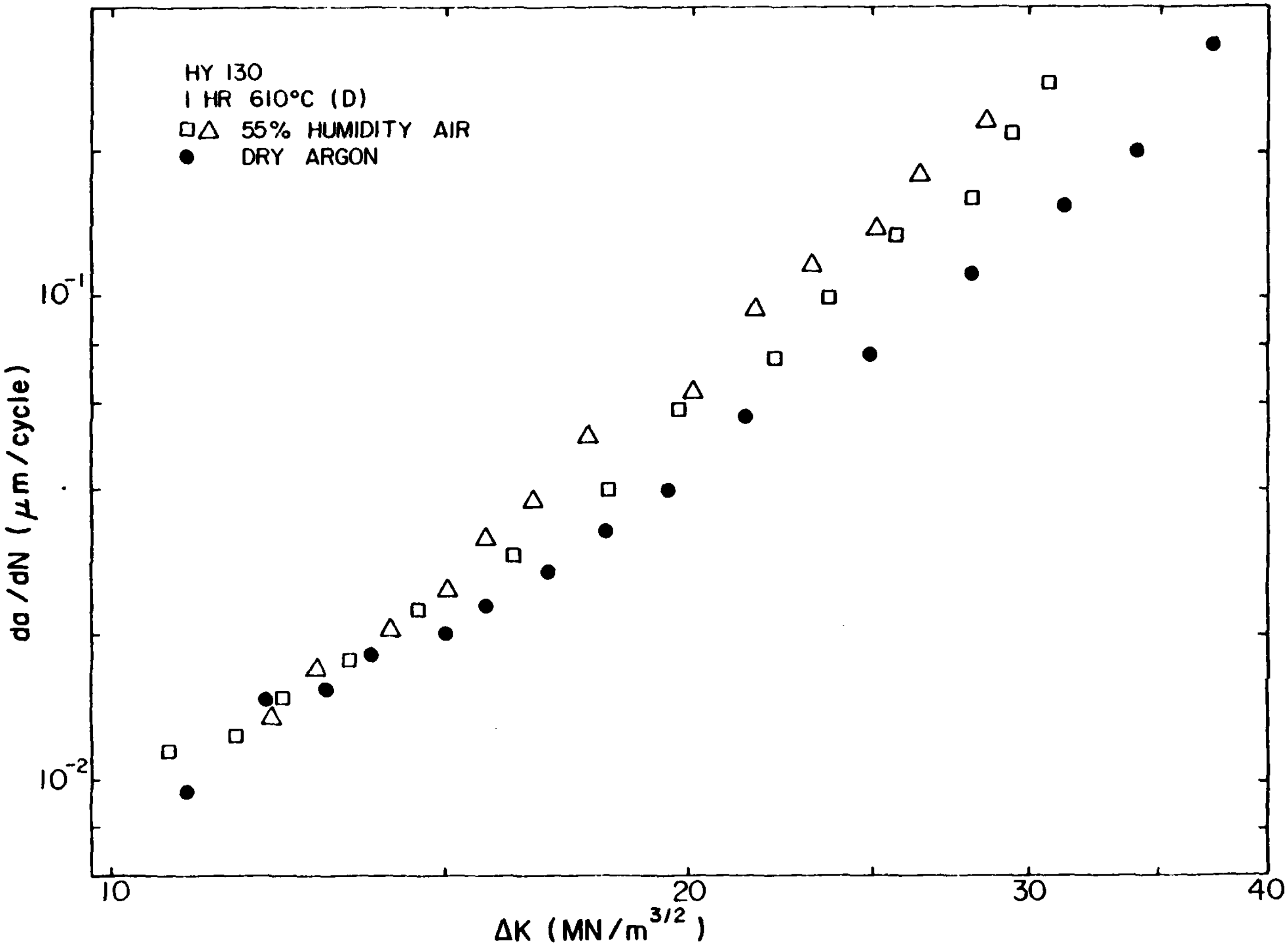

Fig. 5. Fatigue crack propagation rate versus ΔK of HY130 austenitized at 815°C and tempered 1 hr at 610°C.

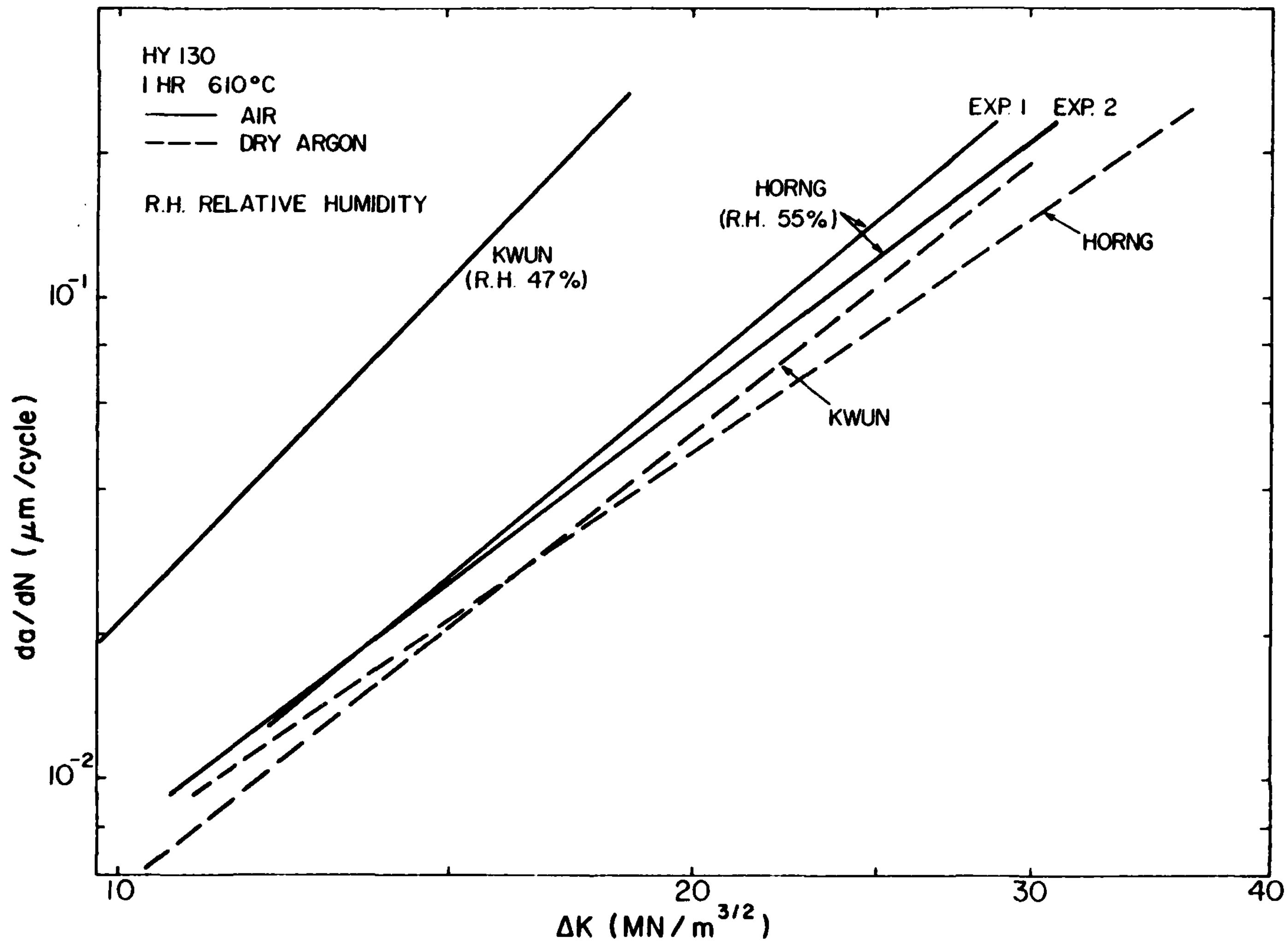

Fig. 6. Comparison of earlier and more recent results for fatigue crack propagation rate of HY130 tempered 1 hr at 610°C. The Kwun results are for samples tempered in a salt pot while the Horng results are for samples tempered in dry argon and drop quenched.